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Lessons from Local to Global Scale

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Chapter 2
The Influence of Logistics Decisions on Transport Decarbonization: Lessons from Local to Global Scale

Lóránt Tavasszy

Abstract One of the proposed approaches to decarbonize freight transport systems is to internalize the environmental costs of transport, by means of carbon emission-based taxes. The expected impact is a reduction of transport demand and an increased use of environmentally friendly transport technologies. The magnitude of the impact will depend on the levels of taxation, the activities to which they apply and the degrees of freedom allowed to companies to react to the taxes. In this chapter we explore the impact mechanisms of carbon taxes by investigating the reorganization responses of freight decision-makers. We do this through a series of empirical cases of recent modelling studies at city, corridor, country, continent and global level. The city case involves an application of an agent-based model to evaluate a carbon credit point system for city logistics. The corridor case involves carbon pricing of container transport in the hinterland of the port of Rotterdam over a multimodal network. The country and continental cases describe the effects of network-wide truck charging, with a focus on mode choice, vehicle type and routing. The global case concerns a full economic impact analysis of internalization of external costs of supply chains, also looking at the effect of changes in sourcing decisions of companies. We draw lessons concerning the impacts of logistics decisions on the impact of policies and identify needs for further research. Common findings relevant for climate change policy include the following: (1) prices needed to achieve a significant impact are a multiple of current market prices, (2) logistics decisions may act as buffer for the propagation of taxes towards consumers and, as a result, (3) the ultimate price impacts for consumers could remain small. In order to be able to predict impacts of climate policies, there is a need to continue research on the way companies take logistics decisions. This includes decisions in specific areas or logistics, but also on decision processes, to better understand the dynamics of impact pathways.

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1 Introduction

The challenge of decarbonizing the global logistics system is a formidable one. The targets for decarbonization were framed by 195 countries in Paris during the 2015 COP21 meeting. Limits have been set on allowed global warming temperatures, and countries have subsequently translated this into national agreements to reduce their carbon emissions. In Europe, the intention was stated to achieve a 60% reduction of carbon emissions by 2050, compared to the 1990 levels. Given that emissions have only increased since then, and still are, the current reduction target is more strict and stands at 83%. Figure 2.1 shows the development of this emission gap at global level, through the decades.

Our focus in this chapter is on the logistics system as contributor to the overall target. Various studies are available in the literature that explain the ways in which carbon reduction can be achieved. The five main strategic routes for decarbonization are as follows (we refer the interested reader to McKinnon (2018) for a detailed discussion):

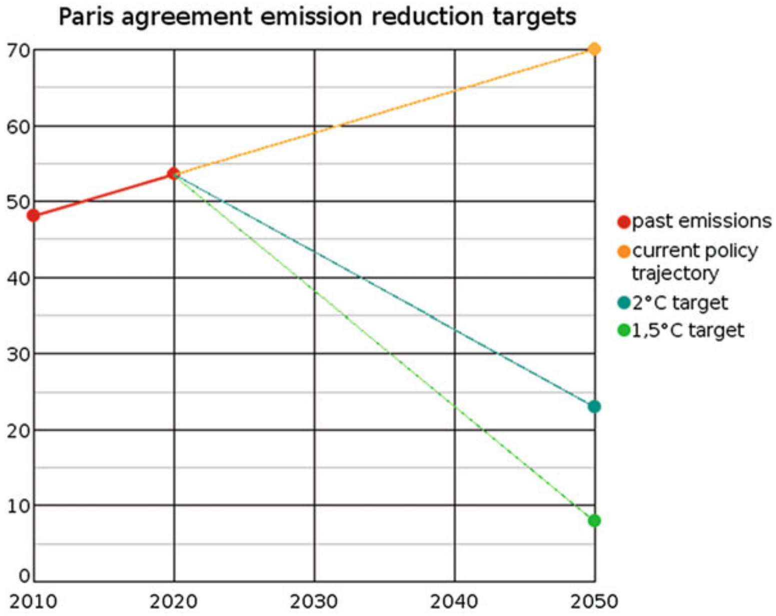

Fig. 2.1 Carbon emission gap. (UNEP 2016)

1. Reduce demand for transport (in volume, weight, distance).
2. Increase the use of least polluting transport modes.
3. Optimize the utilization of transport capacity.
4. Improve fleet energy efficiency.
5. Reduce the carbon content of energy used for transport.

To see that these routes are collectively exhaustive and mutually exclusive, it is helpful to understand the dimensions of each and how they are interlinked. The below equation, akin to the Kaya identity from environmental sciences (Kaya and Yokoburi 1997), demonstrates this point.

$$F = T \cdot M_{\mathrm{m}} \cdot U_{\mathrm{m}} \cdot E_{\mathrm{m}} \cdot C_{\mathrm{m}} \tag{2.1}$$

where

F = carbon emission [$\mathrm{tCO_2}$][1]
T = demand for transport [tonne-km]
M_{m} = share of mode m
U_{m} = utilization of mode m [vehicles/tonne]
E_{m} = energy use of mode m [J/vehicle-km]
C_{m} = carbon intensity of energy source of mode m [$\mathrm{tCO_2/J}$]

The design and implementation of measures to achieve the above changes is not a trivial issue. The logistics system is complex, with many interdependent stakeholders and much uncertainty about future demand and supply of service markets. Also, measures cannot just be forced upon the logistics sector. Private firms act autonomously and decide freely about the choices listed above. Up to a point, the objectives of the market will coincide with the decarbonization objective. Efficiency increases will be welcomed by the sector and will benefit the environment. As long as the measures do not put the demand for products and services at risk, and help to reduce costs, the sector will have a strong incentive to innovate. The costs of abatement of emissions with more radical innovations will be prohibitively large, however, with energy prices being too low to warrant investments in alternatives. Decarbonization beyond simple efficiency improvements will imply a cost increase and a possible reduction of competitiveness of a company. In order to reach the high decarbonization targets, additional measures will be needed to nudge markets to reduce carbon emissions further. One of these measures is the internalization of external costs of logistics, through carbon pricing.

The main policy question that we treat concerns the expected effects of carbon pricing policies on the options above. Our general expectation is that carbon pricing will stimulate change in all the above strategic directions. It could reduce the demand for carbon-intensive products and services and also allow more environment-friendly technologies to become competitive, driving out conventional technologies.

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[1] $\mathrm{CO_2}$ measured in metric tonnes abbreviated here as $\mathrm{tCO_2}$ for the reader's convenience.

There are several approaches to implement carbon pricing through public policies, mostly using the instrument of government taxes. In addition, emission quota or so-called caps may be applied to determine the required level of the tax. If these quotas are company specific, their enforcement can be arranged via a system of permits or certificates, to allow a certain amount of carbon to be emitted. Eventually, permits can be made tradeable, to allow a re-distribution of emissions. In what follows, we will not go into these instruments in more detail and instead represent measures in a stylized way through price increases of logistics services.

Typically, such a policy question can be answered in some more detail using empirical, quantitative, predictive models of logistics systems, reproducing the decision-making of companies. Models can be built that include also dynamic behaviour of firms, so that one can evaluate whether the expected time to impact of carbon taxation is in line with the long-term targets. Modelling of behaviour of firms is not a trivial task. There is little generalized knowledge about how logistics decisions typically will respond to policies. To model them explicitly, we must take recourse to aggregate and stylized models of the freight system, econometrically estimated against observed decisions and flows (Tavasszy et al. 2019). We are not aware of any research about expected time duration of responses of firms to taxation measures; studies are generally static-comparative in nature.

Our objective is to contribute with a comparative discussion of a series of recent modelling studies at city, corridor, country, continent and global level. All the cases relate to the reorganization responses of logistics decision-makers, in the context of carbon pricing. The city case involves an application of an agent-based model to evaluate a carbon credit point system for city logistics. Decisions involved include order size, in-shop inventories, routing and truck type. The corridor case involves carbon pricing of container transport in the hinterland of the port of Rotterdam over a multimodal network. The country and continental cases describe the effects of network wide truck charging, with a focus on mode choice, vehicle type and routing. The global case concerns a full economic impact analysis of internalization of external costs of supply chains, also looking at the effect of changes in sourcing decisions of companies.

The paper is built up as follows. Section 2 introduces a conceptual framework of logistics reorganization measures that firms may take in response to decarbonization policies. We build on this framework of decisions throughout the paper, with empirical cases. In section 3, we present an overview of the cases, in terms of their main characteristics and the general expectations from the literature, concerning lessons to be learned. Sections 4, 5, 6, and 7 each describe a case in itself, at the scale of a municipality, a corridor, nations and the world, respectively. Section 8 synthesizes and discusses the findings across case studies, reaching back to expected lessons stated in Sect. 3. Section 9 concludes the paper with a summary of findings and some recommendations for research and policy.

2 Logistics Reorganization Responses to Carbon Pricing

The term "logistics reorganization response" was, to our knowledge, first suggested in the US Federal Highways Administration's (FHWA's) Freight Benefit-Cost Analysis Study (ICF & HLB, 2002). It concisely expresses the phenomenon that companies will reorganize to try to mitigate adverse effects or reap potential gains of policies on their business. This reorganization takes place by reviewing the relevant logistics decisions and implementing changes. Although the context of the FHWA study was to assess impacts following the principles of benefit-cost analysis, the systematic introduction it provides to impacts on firm decision-making is valuable for our cause. In their classification of effects of policies on society (Table 2.1), it is clear that the responses of firms are an important link in the impact chain of policies, between the primary, or first-order impacts, through business reorganization effects, until the ultimate external impacts that climate policies aim to reduce. In this paper, we are primarily concerned with the logistics decisions of firms and consumers that influence the second- and third-order benefits.

Our aim is to understand how climate policies propagate through the logistics system, by making reorganization responses explicit and studying their impact. The above classification notes the policies as cost-reducing transport policies, and the resulting effects as benefits, in line with the conventional aims of transport policies. In the case of climate change policies, however, the aim is to reduce external effects of transport, mostly by increasing prices or by enforcing the use of more expensive technology. Companies will deploy the same, second- and third-order reorganization measures as before, but will now direct them in a defensive way, to mitigate the impact of cost and price increases. If a company makes smart reorganization decisions, it will (1) reduce the impact of the price increase on the logistics costs of the firm, (2) make the company less sensitive to new increases and (3) reduce the necessary price increase of the service for its clients. Obviously, for policy makers, to be able to assess the final impacts of their climate policies, it is vital that these mechanisms are understood.

A simple example of a reorganization decision that illustrates well the above impacts concerns the choice of shipment size. If a receiver orders small shipments,

Table 2.1 Classification of societal benefits of transport policies (ICF & HLB, 2002)

First-order benefits	Immediate cost reductions to carriers and shippers, including gains to shippers from reduced transit times and increased reliability
Second-order benefits	Reorganization effect gains from improvements in logistics. Quantity of firms' outputs changes; quality of output does not change
Third-order benefits	Gains from additional reorganization effects such as improved products, new products or some other change
Other effects	Effects that are not considered as benefits according to the strict rules of benefit-cost analysis, but may still be of considerable interest to policy-makers. These could include, among other things, increases in regional employment or increases in rate of growth of regional income

Shaded area: focus of this paper

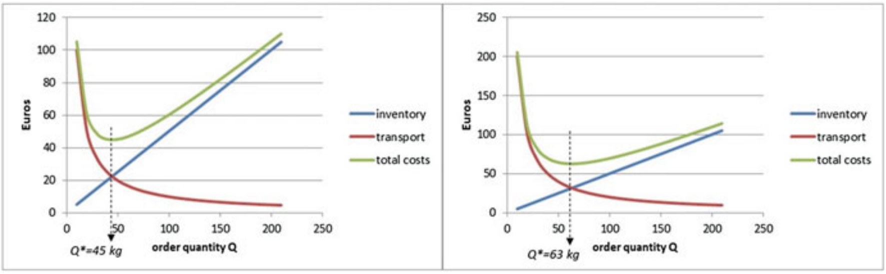


Fig. 2.2 Increase of transport price leading to a change in optimal shipment size Q*

he will typically incur relatively high transportation costs. Not only are there more shipments to move; the unit transport price will typically be higher for smaller shipments. At the same time, stocks will remain small and inventory costs can be kept low. Larger shipments will have the reverse effect. Firms will then optimize their order size, trading off these two cost types. In the case of increased transport prices, the preference will be to order larger shipments, thereby reducing the effect of the cost increase on total costs. Figure 2.2 illustrates this in a stylized case. With transport costs increasing (right figure), the optimal shipment size increases as well.

The total logistics cost increase will be mitigated by this change in shipment size, leading to a lower total logistics cost increase than the original transport price increase (in the above example, a doubling of transport costs leads only to an increase of 50% of total costs). The repercussions of the tax will be that the amount of transport will be reduced (which is a benefit), but the total cost change that propagates into the system will be less than the price change. Similar trade-offs between the transport and inventory cost components can be found in the choice of mode of transport and vehicle type (Combes 2012) or distribution structures (Onstein et al. 2019). The real-world impact of such mechanism on transport flows is significant, as quantified by means of transport price elasticities in Davydenko (2015).

What are the relevant logistics decisions to consider? Riopel et al. (2005) list altogether 48 decisions in logistics management. Based on a condensed list (see Tavasszy et al. 2019), the below table explains their importance for the strategic routes for decarbonization, as mentioned in the introduction. The influence span of each decision area is limited. Interestingly, the choice of mode and transport efficiency are influenced by several decision areas, upstream of the transportation organization decisions. For example, during decisions on production and sourcing, geographical locations are determined which create transport demand – some of these will not allow access to rail and waterways networks. Also, sourcing decisions determine shipment sizes and frequencies, which will constrain the freedom to choose transport modes or to consolidate loads for higher efficiency (Table 2.2).

To conclude, logistics reorganization responses may involve many different decisions in several, vastly different areas of management. Ideally, all these areas

Table 2.2 Relevance of logistics decision areas for carbon pricing

Functional area	Carbon performance dimension and measure				
	Demand for transport (tonne-km)	Choice of mode (tonne-km per mode)	Transportation efficiency (vehicle/tonne)	Energy efficiency (J/vehicle km)	Carbon efficiency of energy (CO_2/J)
Sales and marketing	+	–	–	–	–
Production planning	+	+	–	–	–
Sourcing and material handling	+	+	+	–	–
Distribution channels	–	+	+	–	–
Inventory and packaging	+	+	+	–	–
Transportation organization	–	+	+	+	+

Legend: + influence, – little or no influence

would need to be addressed in order to cover the whole range of decarbonization routes.

In the next section, we introduce the six recent empirical cases in which logistics reorganization responses have been studied.

3 Overview of Case Studies, Foci and Methods

There is a large body of literature on the evaluation of the impact of carbon taxes. Our focus here is on predictive studies, not the normative approaches studying optimal configurations of supply chains (see, e.g. Das and Jharkharia 2018, for a review of these studies). Predictive evaluation studies have been presented at various levels of aggregation, including urban (Anand 2015; Waisman et al. 2013; Marcucci et al. 2018; Cheng et al. 2015), corridor (Winebrake et al. 2008; Zhang 2013), (inter)national (Piattelli et al. 2002; Raha et al. 2003; De Bok et al. 2019) and global level (Lee et al. 2013; Tavasszy et al. 2016; Halim et al. 2019). These used different types of models, falling largely into two categories: transport network models (including mode choice) and spatial/sectoral-economic interaction models (a gravity or CGE type approach). We are not aware of any case that considers decisions on production planning, distribution channel, inventories and fleet technology. The focus, therefore, lies on transport demand and a relatively rich view on transport organization. We distinguish between the following logistics choices:

Table 2.3 Case characteristics

Level	Local	Corridor	State	Continent	Global
Location	City of Rotterdam	Rhine delta	Netherlands	European Union	World
Policy type	Cap-and-trade	Container surcharge	Truck tolls	Truck tolls	Full internalization
Logistics decisions[a]	S, V, R	M, T, R	V, R	M, V, R	S, T, R
Dynamics	Event based	None	None	None	None
Modelling approach	Agent based simulation	Supernetwork choice	Discrete choice model	Discrete choice model	Linked SCGE and supernetwork
Source	Anand (2015)	Zhang et al. (2013)	De Bok et al. (2020)	Raha et al. (2003)	Tavasszy et al. (2016)

[a] **S**ourcing and sales, **M**ode of transport, **T**ranshipment location, **V**ehicle type, **R**oute choice

- Sourcing and sales of goods, resulting in trade (S)
- Mode of transport for inland modes (M)
- Transhipment terminals inland and for maritime traffic (T)
- Choice of vehicle type (truck size and engine type) (V)
- Route choice over the transport network (R)

Table 2.3 shows the detailed characteristics of the cases.

The policies considered are in one sense quite similar, as the main intervention in all cases is a tax per emitted tonne CO_2 applied to units of transport performance (tonne-km, vehicle-km or TEU-km). However, there were subtle differences in the mode of implementation. The case of the city of Rotterdam involved a limitation in the total volume of emission rights, to be distributed among all companies. Trading of these rights was made possible. The other cases did not involve a cap, but prices were varied in different ways. Case 2 varied prices to identify the tipping points in the system. Case 3 and 4 based the prices on the current markets for external effects, using principles of social marginal costs (case 3) or average market prices, insofar available (case 4). Case 5 extended well beyond carbon prices and included an internalization of other external costs as well including various emissions and safety costs of transport.

The cases differ in terms of the models used and the choices represented in these models. Case one was built on an agent-based model, where shopkeepers were the main decision-makers, deciding about order size (weighing transport costs against inventory costs) and type of vehicle (in effect, the carrier being either the legacy carrier or a common carrier using electric vehicles). Carriers would decide about their routes, combining shops served by round trips in the most efficient way possible. This is the only case in which dynamics was included, where the factor time in the model was driven by events of decision-making (which were assumed to have a fixed frequency) and by transport operations (the execution of which costs time). The second case uses a multimodal network (supernetwork) formulation to identify routing of flows in the hinterland of the maritime port of Rotterdam, the Netherlands, based on customer preferences for different types of services, by different modes. Case 3 concerns two applications of a very similar nature, one at national and one at international level. Both involved a relatively light form of truck pricing and involved responses for changes in vehicle types and routes driven. Case 4 also involved network choices (related to routes of transport including ports), but was linked to a model of trade relations between regions and sectors over the world.

In the next sections, we introduce each case and discuss the results of the applications.

4 Carbon Credit Points for City Logistics

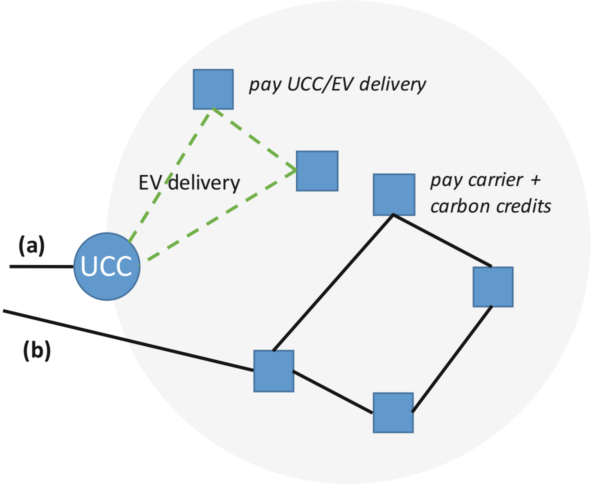
The decarbonization solution for urban areas developed by Anand (2015) involves the case of a city trying to influence the external effects of freight distribution within its borders. It sets out a policy around a cap-and-trade policy for carbon emissions. Carbon permits are issued to all carriers entering the city; each trip into the city requires the use of one carbon credit point. As the number of points is limited (capped by the maximum volume of carbon emissions that the city wants to allow), the city government provides an alternative mode of shipping. An Urban Consolidation Centre (UCC), at the border of the inner city area, can be used to deposit freight destined for the city. From here, electric vehicles of a carrier concessioned by the city will take the freight to its destination. No petrol or diesel vehicles are allowed to enter the city, without accompanying carbon credits. As soon as all credits have been spent, remaining trips must be made via the UCC. Companies are allowed to trade carbon credit points. The price for trading in this scheme is set by the local government; the revenues are collected by government and recycled as a subsidy for the UCC. Credit points are perishable so that carriers cannot accumulate them (Fig. 2.3).

The situation was modelled using an agent-based formulation, where agents in a city (government, shopkeepers, carriers, UCC) made decisions. The decisions were aimed at achieving agent-specific objectives, were cyclical (i.e. reviewed with a fixed frequency) and, eventually, interdependent. The objective of government was to reduce the emission levels to a certain target level. Shopkeepers would aim to minimize their costs (demand being assumed fixed), just like carriers, while the UCC aimed to achieve a net financial result.

Decisions considered included the following (Fig. 2.4):

- Government: number and price of carbon credits, subsidy to UCC; monthly decision
- Shopkeepers: order size, carrier to use – daily decision
- Carriers: routing; daily
- UCC: price of transport with EV; monthly

Fig. 2.3 Lay-out of city logistics case



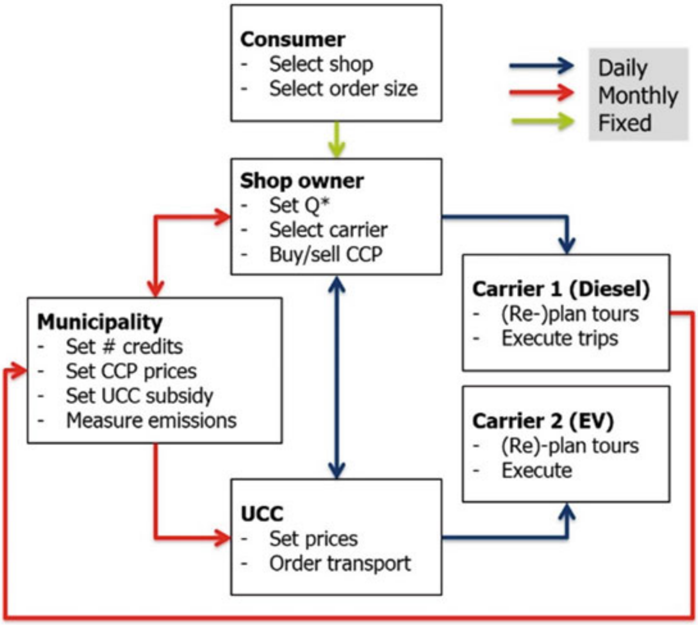


Fig. 2.4 Interrelated decisions of actors. Legend: review frequencies

One emergent property of the model that was of interest concerned the time that it would take for the target (a reduction in kilometres driven by conventional vehicles) to be reached. This required all the actors to align their decisions. The results were

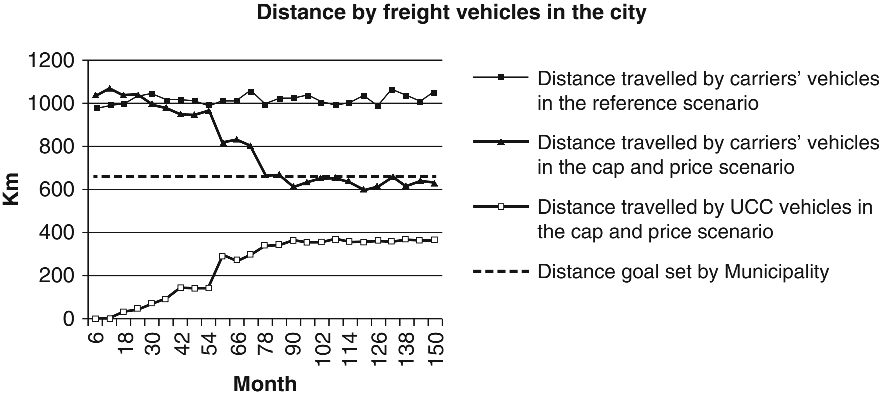


Fig. 2.5 Example of result of convergence to emission target. (Source: Anand 2015)

surprising in the sense that it would take years to reach the new equilibrium. Obviously, simple solutions could be found by increasing the frequency of decision-making of the government about CCP and UCC prices or even installing the equilibrium price at the outset. This would however force agents to have such a strong increase in costs at the short term that business continuity could be threatened. The main point, however, was that this model proved instrumental to predict the response time of the system (Fig. 2.5).

5 Hinterland Container Transport Corridor

The case of pricing in hinterland corridors was studied by Zhang (2013). She considered mode choice for the transport of containers between maritime ports and hinterland destinations. Depending on the destination, up to three alternative modes of transport are available: road, rail and waterways. Pricing policy was implemented as an additional variable transport charge for road transport, calculated via a carbon price. The main questions were (1) what price would be needed to create a significant shift of flows away from road transport to other modes and (2) which effect of CO_2 emission reduction could be achieved. Besides the decisions of shippers and forwarders about the mode of transport, also decisions on network design were considered. More specifically, terminal locations were regarded as flexible. As the policy would be implemented over the longer term, this strategic decision was included in the model.

The problem was modelled using a bi-level optimization approach, with service demand being determined by simulation of choices for the mode and route in a supernetwork (i.e. a fully connected multimodal network including terminals) and with network design being determined by an optimization model, solved using a

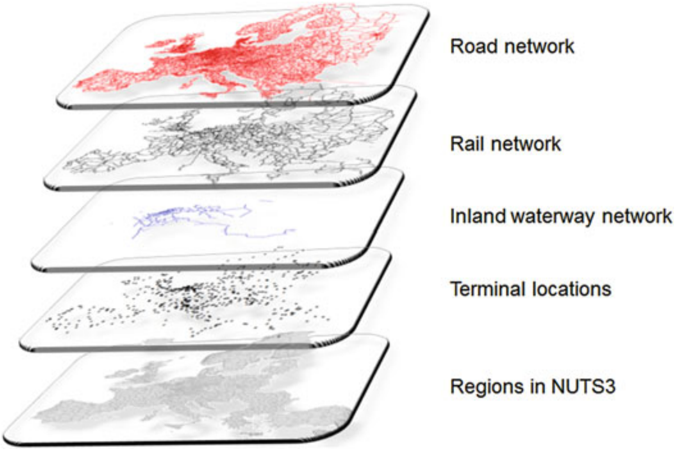


Fig. 2.6 Visualization of the supernetwork. (Zhang et al. 2013)

meta-heuristic based solution algorithm. The procedure is described in detail in Zhang (2013) (Fig. 2.6).

Subsequently, emission-based variable charging was introduced for all modes of transport. Users of the network would reconsider their choice of mode, based on the new price, and the network design would adapt to best serve demand. The emission charge was varied up to 1000 Euro/tCO_2. An optimum was found for a price of 150 Euro/tCO_2, where emissions had reduced by 20% compared to the base case. A higher price did not yield a lower emission level, implying that carriers had exhausted the opportunities to move to another mode of transport. Note that revenues were not recycled into the system.

The finding that emission-based pricing in hinterland freight systems can be reasonably effective up to a certain point has, to our knowledge, not been found elsewhere. Interestingly, the optimal price is not a very steep one. With an emission factor of 100 gCO_2eq/ton-km, a load of 10 tonne per container and a distance of 1000 km into the hinterland, the added price is 0,15 Euro per km., which is reasonably in line with the current policy proposals in the Netherlands – a mark-up of roughly 15% on the current trucking prices. Note that in this case, it seems safe to assume that the hinterland container transport market is decoupled from the logistics of the global supply chains using them, so that indirect efficiency impacts (changing shipment sizes, bundling of freight, adapted warehouse locations) can be neglected. As we will see in the case of national transport, however, this assumption is not a trivial one.

6 National and EU Road Networks

In this section, we report two transport model applications that were similar in nature but applied with slightly different models and at different spatial levels. Their comparison provides interesting insights for both cases. The first involves the large-scale network of the European Union. Although somewhat dated, the exercise is still unique in terms of the rationale of the policy and the scope of responses considered. The policy aimed to internalize external costs by means of a marginal external cost-based truck charging scheme. Marginal social costs were made dependent of the type of road, synthesizing external costs from various cost sources. Figure 2.7 shows the levels of external costs that coincided almost in a linear fashion with population density.

The model concerned the SCENES model of European passenger and freight transport (Raha et al. 2003). Besides the usual response of mode shift, also changes in vehicle type choices and trade relations were allowed. The effects of the truck charge differed by commodity type. All effects combined (mode, vehicle type, route) resulted in reductions in transport performance of up to 20% (Fig. 2.8). It is worthwhile to note that basic bulk products are relatively sensitive to transport price changes. Here, transport price has a relatively high share of the product price, and transport time is less important. Hence, shippers and carriers will be more inclined to respond and sacrifice service quality.

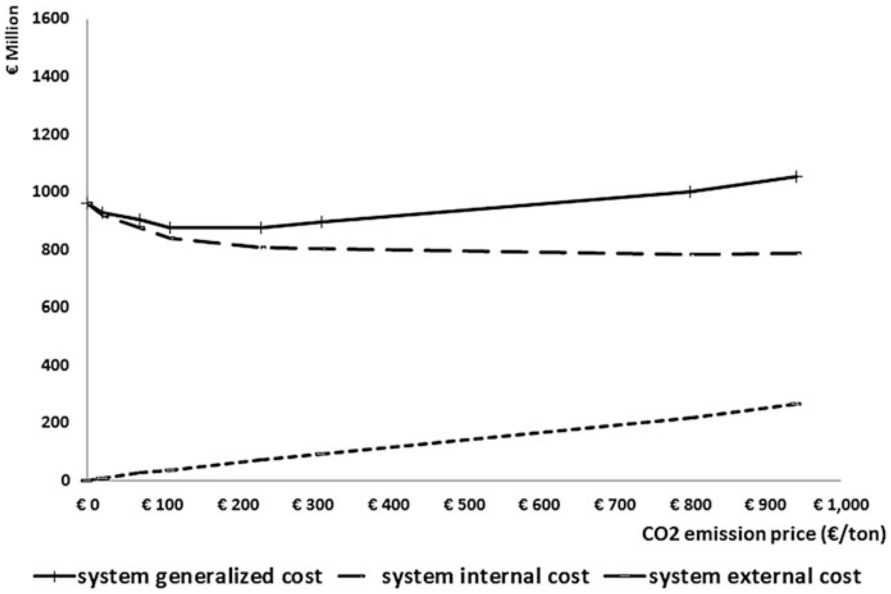


Fig. 2.7 Cost functions for internal, external and total costs. (Zhang et al. 2013)

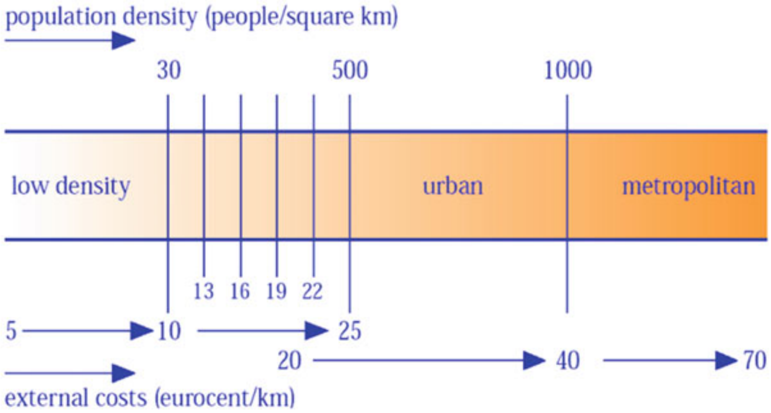


Fig. 2.8 External costs calculation related to urban density. (Raha et al. 2003)

A second case involves the most recent analyses of a Dutch variable road pricing scheme (MuConsult 2018). This study involved the use of expert judgement and the Dutch national freight transport model, BASGOED, for the assessment of impacts on transport flows. It was assumed that part of the charges would be absorbed by efficiency improvements in the logistics process, without detailed consideration of the background of these changes. The remaining part of the charges would propagate to the shippers and lead to changes in mode choice and trade patterns, similar as in the EU case. The idea that carriers would work more efficiently in response to the charges was based on the assumption that they would use larger trucks and transport bigger shipments. This conforms to the EOQ principle, which dictates that firms will order bigger shipments to reduce the costs of transport. The choice of shipment size, however, was not part of the model. In an additional exercise (De Bok et al. 2019), this effect was studied simultaneously with the choice of vehicle type. The finding was that the efficiency effect indeed existed, but was less prominent than assumed before. Increasing shipments create larger inventory costs for firms and will therefore restrain the increase of shipment size.

7 Global Supply Chains

At the global level, decarbonization through pricing is a major challenge, due to international competition. Choices made in response to pricing policy by consumers, producers and logistics service providers may lead to shifts in trade or transport activities from one country to another. A policy where countries price differently, and some not at all, may induce shifts of activities to so-called pollution havens. There have been few evaluations of a worldwide pricing policy on global trade and transport (Lee et al. 2013; Zeshan and Ko 2016); these have not considered impacts of a full internalization on both trade, economy and network flows. The policy

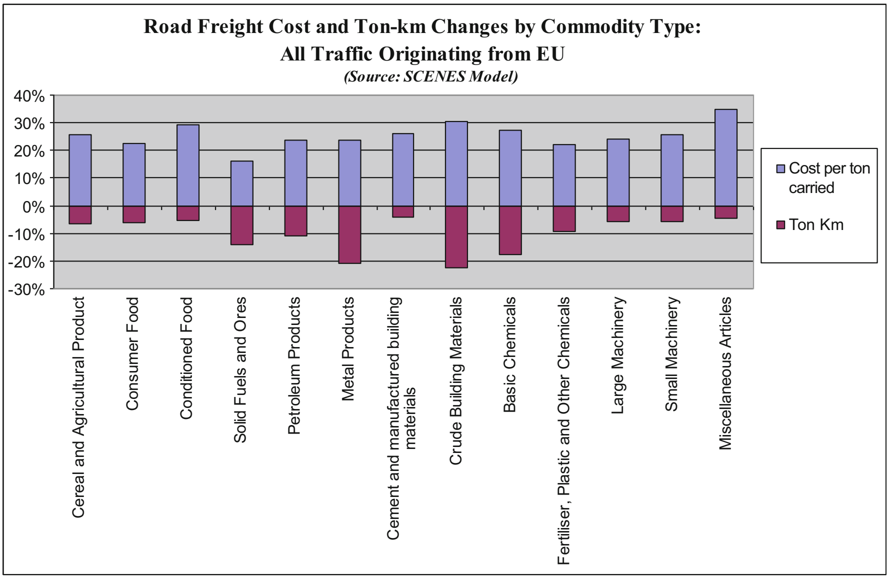


Fig. 2.9 Impacts of external costs based road user charges in the EU. (Raha et al. 2003)

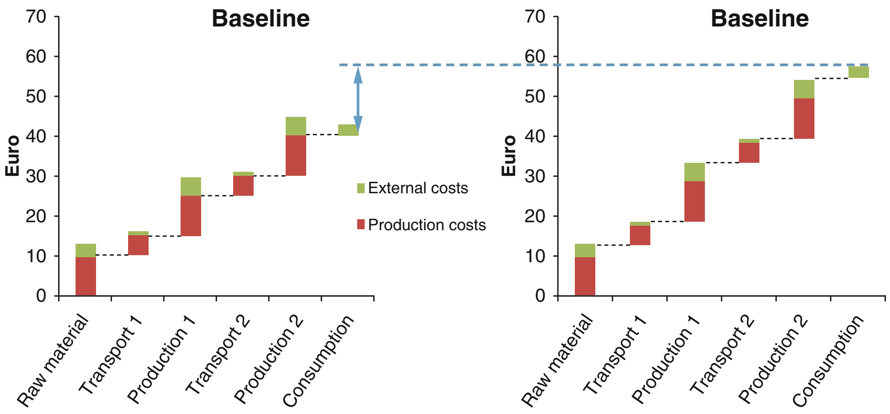


Fig. 2.10 Illustration of supply chain based internalization of external costs

evaluated in this case involved an internalization of all external costs in supply chains and is reported in more detail in Tavasszy et al. (2016). External costs associated with various types of health effects were included, going far beyond carbon emissions (environmental externalities and social externalities including noise, congestion and traffic safety). Figure 2.9 shows the principle of adding external costs to product prices in the entire supply chain. Eventually, consumers will be charged the full external costs (Fig. 2.10).

Table 2.4 Impact of world trade and transport of internalization of external costs

Sectoral added value (USD)	Impact (2040)
Agriculture	−4.2%
Food and feed	−0.2%
Solid fuels	−1,1%
Oil	−0.9%
Ores and scrap	−0.6%
Metals	−0.3%
Building materials	−1.0%
Fertilizers	−0.9%
Chemicals	−0.7%
Manufacturing	−0.3%
Overall impact on global trade (USD)	**−0.9%**
Impact on Rotterdam's throughput (TEU/y)	**−0.5%**
Impact on CO_2 emission (ton)	**−27%**

To evaluate changes in world trade, a macro level model of global supply chains was used, in the form of a Spatial Computable General Equilibrium (SCGE) model of the global economy. The SCGE model EXIOMOD (Ivanova 2014) was linked to a network model (Tavasszy et al. 2011) to understand changes in the global routing of transport flows. The internalization scenario produced a new global economic equilibrium for production, consumption and trade, and the network assignment showed how these new trade flows would affect main maritime ports in the network, such as the port of Rotterdam. Table 2.2 summarizes the results of the calculations for the Netherlands.

The trade of traditionally environment unfriendly sectors such as agriculture (particularly meat production), non-renewable energy and building materials would suffer most, but only at a relatively modest rate of up to 4.2% aggregate growth of value added over a period of more than 25 years. The overall impact on global trade would amount to less than 1% over this period, and port throughput would be reduced only by 0.5%. Emissions would be 27% lower, however, than the baseline volumes in 2040 (Table 2.4).

Although this may not seem a big change compared to the targets set for global emission reduction, one should bear in mind that the reduction was achieved with current market prices for all external costs. An interesting finding, therefore, is that the long supply chains, in effect part of an extensive network of sectors within the economy, are able to adjust fairly effectively. While the many small adjustments all absorb part of the price increase, the net increase at the end of the chain is small. The additive effect of emission reductions, in line with the internalization concept, is high, however.

8 Synthesis and Lessons from Cases

The main lessons across the cases concern a number of topics; we discuss these below:

- Importance of understanding logistics decisions
- Results suggest trade-off between acceptance and impact
- Identified gaps in research

8.1 *Importance of Understanding Logistics Decision-Making*

The cases presented vary widely in terms of the logistics decisions considered. The exact influence of every decision on the entire impact chain – between truck costs and truck volumes – is still largely uncharted territory. Systematic reviews of price elasticities of road transport flows do exist (de Jong et al. 2010; Beuthe et al. 2014), but only give a partial account of decisions, as focusing on mode choice-based price sensitivity. As we see from the national cases, however, it is important to include aspects such as inventories and logistics efficiency. Also, the choice of vehicle type is relevant. This series of logistics decisions can act as a buffer in the impact chain, dampening the effect of price increases. Only recently, new elasticities on distribution channel-redesign have been investigated (Davydenko 2015). For many other logistics reorganization responses, the impact at a macro level is unclear. A separate issue concerns the degree to which carriers van transfer the price increase to their clients (Holguín-Veras et al. 2015). More work is needed that describes the behaviour of a population of consecutive logistics decision-makers.

One consequence of the long chains of decision throughout the supply chain is that price increases will be absorbed to a large extent by the time they reach the consumer. The global case shows clearly that the intersectoral networks allow many options to replace polluting products and services by those that pollute less – to an extent that the final effects will hardly be felt. This effect also appeared in another comparable study (Lee et al. 2013).

8.2 *Trade-Off Between Acceptance and Impact*

All studies indicate that current market prices for external costs are too low for internalization to work through in significant reduced carbon emissions. The corridor case study shows that carbon prices need to be an order of magnitude above the prices of this decade (at current, European Emission Allowance prices are varying roughly between 5 and 30 Euro per tonne). Above levels of 150 Euro/tCO_2, transport activity proved relatively unresponsive again, suggesting that the 20% reduction is the feasible potential for a hinterland network with sufficient options available over water and by rail. The current market prices, roughly translated into the charge calculations in the Dutch and the global case, had a minor impact. The EU variable charge was based on a systematic account of total external cost and had a significantly higher impact. Clearly, if one wants to arrive anywhere near a contribution to global emission targets, higher charges have to be considered than what is now considered politically feasible.

8.3 Gaps in Studies

The studies described here are representative of the broader extant literature, in terms of the scope of decisions considered, but relatively rich compared to mainstream research. We have shown that it matters for the result of impact assessments, which reorganization responses are included in studies. A number of important gaps in modelling would need to be addressed. Firstly, many decisions that could have a mitigating effect on industry responsiveness are still missing in most studies, like distribution chain design, outsourcing of logistics services and shipment sizes. Secondly, more insight is needed in the distributional effects of policies towards specific sectors and regions of the world. These may be large and may require additional policies to promote acceptance of decarbonization. Thirdly, the calculations seem to indicate that the level of decarbonization needed in the sector of around 80–90% will not be achieved by taxing current technologies. None of the studies presented here and, to our knowledge, no other work in the extant literature arrives at decarbonization results of this scale. The question, therefore, how a drastic decarbonization can be achieved, is not answered. Finally, the issue of dynamics seems to be a weak spot in the literature – while assumptions about dynamics are essential to predict times to impact of policy measures, we are essentially still in the dark. We note, finally, that a comprehensive literature review would be needed to confirm the above issues that we have only been able to touch upon briefly with these cases.

9 Concluding Remarks

The purpose of this chapter is to explore ways in which logistics decisions can be taken into account in evaluations of decarbonization policies. To this end, we reviewed and compared several cases of quantitative policy evaluation, all implementing a form of taxation on transport, with the aim to reduce external effects. The cases underline a number of general lessons. Firstly, logistics decision-making is important to be understood as they determine the reorganization response of companies. The current literature on logistics decision-making is too narrow in scope to cover the necessary range of relevant choices and their properties. Additional research is needed to be able to predict impacts of carbon taxes. Typical balancing mechanisms in logistics such as the trade-off between transport and inventory costs, and empirically difficult questions such as decision dynamics, should be prioritized for research. Secondly, from a policy perspective, the level of carbon prices necessary to push emissions in the system downward are an order of magnitude higher than the current market prices. For policy makers, this suggests that attention is needed for the public acceptability of effective carbon taxes, or other non-fiscal measures aimed at an equivalent impact. Thirdly, as logistics decisions are multi-faceted and supply chains include many companies, the impact chain between tax measures and emission volumes is long. This implies that the ultimate impact on consumers of carbon taxes can be small, while the added effect of emission savings is expected to be relatively large.

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